THE AUDITORY AND VESTIBULAR CONSEQUENCES OF TRAUMATIC BRAIN INJURY AND THE ROLE OF THE AUDIOLOGIST ON THE INTERDISCIPLINARY MANAGEMENT TEAM

CAPSTONE PROJECT

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Audiology in the Graduate School of The Ohio State University

By

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2013

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ABSTRACT

Traumatic brain injury (TBI) results in disruption of normal brain function and the severity of injury can vary depending on the nature of the brain injury. Individuals who have experienced a TBI may be at increased risk of both auditory and vestibular deficits. These auditory and vestibular consequences associated with TBI can negatively impact an individual's life. Often, auditory and vestibular symptoms are considered secondary to other primary medical symptoms associated with TBI. However, due to the potential negative impact auditory and vestibular deficits can have on the overall rehabilitation process for individuals with TBI, the audiologist is an important member of the interdisciplinary management team to diagnose and provide rehabilitation services for TBI patients and their families.

DEDICATION

This document is dedicated to my parents, Jeff and Teri Wintrow. Thank you for accompanying me on this journey and for your unwavering love and support along the way. This document is also dedicated to the brave men and women of the armed forces with whom and from whom I have had the great privilege to work and learn over the past year. The lessons you have taught me go far beyond audiology and have forever altered my outlook on life.

ACKNOWLEDGMENTS

I would like to acknowledge the faculty and staff of The Ohio State University Speech and Hearing Department for their support and guidance during the Au.D. program. I would especially like to thank my advisor, Dr. Christina Roup, Ph.D. for her unrelenting encouragement and patience during the capstone process.

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CHAPTER 1

INTRODUCTION

Traumatic brain injury (TBI) is a type of acquired brain injury that occurs when a sudden trauma causes damage to the brain (National Institute of Neurological Disorders and Stroke [NINDS], 2002). TBI can be caused by direct impact of an external force to the head, a jolt of the head, or penetration of an object through the skull. Each of these traumatic events can lead to disruption in normal brain function. These abnormalities in brain function can have a negative impact on many aspects of an individual's life: physical, cognitive, social, and emotional. TBI severity can be categorized as mild, moderate, or severe. Mild injury typically refers to a brief change in mental status or consciousness, where a severe injury typically results in an extended state of unconsciousness or amnesia following the injury [Center for Disease Control and Prevention (CDC), 2010]. Depending on where the injury occurred in the brain, there are a number of secondary injuries or symptoms that may occur. Some secondary symptoms of TBI include but are not limited to: headaches, nausea, blurred vision, dizziness, ringing in the ears, aphasia, and trouble with memory and attention. These symptoms will vary depending on the individual and the severity of the brain injury.

It is estimated that nearly 1.7 million individuals in the United States suffer from a TBI each year, making it one of the leading causes of disability in the country (CDC, 2010). TBI can be caused by falls, gunshot wounds, car accidents, blast injuries, and violence. In particular, there has been an increase in TBI over the past several years in elderly individuals from falls and armed force members returning from combat in Iraq and Afghanistan with blast-related injuries.

For some individuals there is an association between TBI and auditory and vestibular dysfunction. The TBI-inducing trauma may lead to disruptions in the peripheral and central auditory pathways and can also disrupt the vestibular pathway. These disturbances can often lead to significant hearing or balance impairment for the individual. Due to the complexity of TBI, auditory and vestibular dysfunction can often be considered a subtle impairment (Munjal et al., 2010b). However, in the same way medical impairments can affect an individual's quality of life so can a hearing or balance impairment. In addition to quality of life, hearing and balance impairments can also affect the patient's success any other areas of rehabilitation. For example, not being able to hear the speech-language pathologist during a therapy session can delay the rehabilitation process. Therefore, it is important for the audiologist to be a member of the interdisciplinary team who is responsible for the successful rehabilitation of the individual with TBI. This review of the literature will examine the auditory and vestibular consequences associated with TBI and the role of the audiologist in the diagnosis and management of these consequences as part of an interdisciplinary team.

CHAPTER 2

THE AUDIOLOGICAL AND VESTIBULAR CONSEQUENCES ASSOCIATED WITH TBI

The consequences of a traumatic brain injury are unique to the individual patient. This is due to the variety of ways that TBI can be acquired, the variety of classifications of the severity of the injury, and unique characteristics of the individual who acquired the injury. Because of the variability of TBI it is not surprising that the audiological and vestibular symptoms will also differ for each individual. Some individuals may have only dysfunction of the auditory or vestibular system where as others may suffer dysfunction of both systems. In addition, not all auditory symptoms will be the same for individuals with TBI. Auditory dysfunction can stem from the outer, middle, and/or inner ear. The central auditory system may also be affected. The same can also be said for the vestibular system. The variability in symptoms makes it imperative that the audiologist be cognizant of all the consequences of TBI.

Outer and Middle Ear

Depending on the type of head trauma that is sustained there can be damage to the outer ear. For instance, an individual who has sustained a head injury from a car accident or from a blast-related incident may have come in contact with flying debris. This debris can leave the pinna damaged or burned (Fausti et al., 2009). Patients with burns to the pinna or any other area of the body are often treated with infection-controlling antibiotics and are at risk of ototoxic sensorineural hearing loss (Myers et al., 2009). If the damage to the pinna is severe enough, it may cause malformation or complete absence of the pinna. Flying debris or shrapnel from a bomb blast can become lodged inside the ear canal and lead to otitis externa if not treated by antibiotic eardrops. If hearing sensitivity is not preserved following the TBI, damage or absence of the pinna can have implications for the type of amplification an audiologist may recommend for these patients. If a TBI patient has a damaged or absent pinna conventional amplification may not be appropriate and alternative options may be considered, such as a bone anchored hearing aid.

In addition to damage to the outer ear, TBI-inducing trauma can also affect the middle ear. Damage to the middle ear may result in tympanic membrane perforation or a discontinuity of the ossicular chain. The most common middle ear dysfunction associated with TBI is tympanic membrane perforation (Basson & Van Lierop, 2009). Some perforations may only be small while others may involve the complete destruction of the tympanic membrane. Perforations associated with TBI can cause temporary conductive hearing loss and typically heal on their own without surgical intervention. If the perforation is large or does not heal on its own, complications can occur. For example, if small fragments of the squamous epithelium enter the middle ear space following the tympanic membrane rupture, these cells can grow into cholesteatomas (Fausti et al., 2009). Cholesteatomas can also result in conductive hearing loss and may require surgical intervention from an otologist.

In some cases of tympanic perforation associated with TBI, the perforation heals completely but a conductive hearing impairment still remains. In this case, the audiologist should be suspicious of ossicular chain discontinuity. This involves the disruption in connection between the bones within the middle ear: the malleus, incus, and stapes. For example, in the case of blast-related TBI the pressure wave from the blast can dislocate, distort, or fracture of the ossicular bones (Myers et al., 2009). If this disarticulation occurs, the bones do not effectively transmit the sound vibrations to the cochlea. There are several different disarticulations or fractures that can occur. They include: incudomalleolar disarticulation, incudostapedial disarticulation, dehiscence of the incudostapedial joint, and fracture of the stapes (Barron & Van Lierop, 2009). Any type of ossicular discontinuity can lead to a conductive hearing loss. Most often these injuries can be repaired through surgical intervention involving the use of prosthetic devices to repair the connection between the disarticulated bones. Tympanic perforation and ossicular chain damage may disperse some of the energy transmitted by the pressure wave, protecting the inner ear. Conversely, a pressure wave from a blast injury can damage the inner ear without causing damage to the ossicular chain (Fausti et al., 2009).

Temporal Bone

The temporal bone of the skull houses both the auditory and vestibular end organs. Fracture of the temporal bone is a common manifestation of head trauma. There are two classifications of temporal bone fractures: longitudinal and transverse. Longitudinal fractures compromise about 80% of the all temporal bone fractures (Podoshin & Fradis, 1975). These fractures are often caused by blows to the temporal or parietal areas and course lengthwise. The fracture usually courses through the posterior and superior walls of the bony ear canal, travels across the roof of the middle ear, and ends in the middle cranial fossa (Cannon and Jahrsdoerfer, 1983). The type of hearing loss most often associated with longitudinal temporal bone fractures is conductive in nature. Conductive hearing loss due to longitudinal fracture is most often caused by disarticulation of the ossicular chain caused by the fracture. Transverse fractures compromise the remaining 10-20% of temporal bone fractures. These fractures are typically caused by blows to the frontal or parietal areas and run perpendicular rather than parallel to the petrous pyramid. The fracture line begins in the foramen magnum and ends in the middle cranial fossa (Cannon and Jahrsdoerfer, 1983). Transverse fractures often disrupt the otic capsule causing, most commonly, a sensorineural hearing loss (Lyos et al., 1995). Hearing loss associated with both types of temporal bone fractures are typically unilateral depending on which side of the head the trauma occurs on; however hearing loss can be bilateral. Degree of hearing loss will also vary depending on patient factors such as previous history of hearing loss and severity of the head injury. It is important to note that not all TBIs result in temporal bone fractures. In addition, auditory and vestibular dysfunction can be observed in TBI cases without temporal bone fracture but with other skull fractures or brain concussion (Podoshin & Fradis, 1975).

Inner Ear

Damage to the inner ear, specifically the cochlea, due to trauma resulting in TBI most often leads to a permanent sensorineural hearing loss. In some cases, temporary threshold shifts can be seen. Temporary threshold shifts most often occur when the head injury is associated with a high level of noise such as a blast or the noise associated with a car accident; however permanent sensorineural hearing loss is most common in these situations. Transverse fracture of the temporal bone is associated with the highest rate of cochlear injury compared to other skull fractures and brain concussions (Podoshin & Fradis, 1975). The frequency of sensorineural hearing loss associated with TBI varies. Munjal, Panda, and Pathak (2010a) reviewed the auditory deficits of a group of individuals who obtained head trauma from car accidents. They found that the most observed hearing loss was high frequency sensorineural hearing loss that varied in degree. In another study completed by Lew et al. (2007), individuals with both blast and non-blast related TBIs were examined and it was found that 44% of individuals with non-blast related TBI had a hearing loss and of that percentage 47% had a sensorineural hearing loss. Of those individuals with blast related TBI, 62% reported hearing loss and of those individuals 58% had a sensorineural hearing loss. In addition, Munjal, Panda, and Pathak (2010b) reported that as severity of TBI increased the incidence of high frequency sensorineural hearing loss also increased.

There are several pathogenic mechanisms that can produce sensorineural hearing loss due to TBI-inducing trauma. They can include: direct trauma to the cochlear nerve, disruption of the membranous labyrinth, and vascular compromise (Lyos et al., 1995). Brain injury associated with a blast can lead to damage to the inner and outer hair cells, where the force of the blast wave tears the sensory cells and has the potential to displace the basilar membrane (Fausti et al., 2009). This damage is what leads to the increased prevalence of high frequency sensorineural hearing loss associated with brain injury. In some cases the sensorineural hearing loss can be progressive. Lyos et al. (1995) suggests that progressive sensorineural hearing loss after a brain injury is most likely due to a perilymphatic fistula or development of endolymphatic hydrops. Lastly, an indirect audiological consequence of brain injury can occur from ototoxic medications. Due to the nature of many brain injuries and the fact that other body systems can also be injured at the same time, it is not uncommon for individuals to be treated with ototoxic medications. For example, aminoglycoside antibiotics can be administered to brain injury patients to combat infection but they can also cause irreversible cochlear or vestibular damage (Fausti et al., 2009). This can be especially troubling for combat veterans with brain injuries that have also had noise exposure as previous noise exposure increases the risk of ototoxic sensorineural hearing loss (Fausti et al., 2009). The likelihood of preexisting hearing loss due to noise exposure puts veterans with TBI being treated with ototoxic drugs at an even greater risk; that is, further loss of hearing can immediately exacerbate communication impairment and reduce post-treatment quality of life (Fausti et al., 2005).

Central Auditory System

While peripheral hearing impairment is a common consequence associated with TBI, even more common is individuals with normal or near normal hearing sensitivity complaining of functional hearing impairments that are not in agreement with the pure tone audiogram. These complaints suggest that auditory deficits may be occurring within the central auditory system. It seems obvious that central deficits could easily occur in individuals with TBI due to the impact of the brain against the skull or in cases of penetrating brain injuries the temporal lobe, which contains the auditory cortex, could be directly damaged. Musiek, Baran, and Shinn (2004) hypothesized that in cases of closed head injuries, the central auditory pathway is affected more than the peripheral pathway. It is likely that the deformation and acceleration/deceleration of the brain within the skull results in primary injuries such as contusions and concussions and secondary injuries such as ischemia and increased intracranial pressure (Musiek, Baran, & Shinn, 2004). These injuries could cause damage to any portion of the auditory pathway, from the brainstem to the cortex.

Any damage to the delicate connections within the auditory brainstem can lead to significant central auditory deficits. One of the roles of the auditory brainstem is to provide sensitivity to the fine temporal structure of the auditory stimuli (Fausti et al., 2009). The fine temporal structure allows the listener to identify information about pitch and improves processing of sound in the presence of interfering sounds such as background noise. Connections within the auditory brainstem are also responsible for binaural processing. The brainstem is responsible for comparing information that is being transmitted from both ears and using it to localize sounds and to distinguish between multiple sound sources and organizing that information into a meaningful auditory signal (Fausti et al., 2009). Listening in groups of people or in background noise is one of the chief complaints that individuals with head injuries report. There are a number of other central auditory deficits that can be seen in individuals with head injury including: difficulties understanding individual's with rapid speech, slower processing time of auditory information, difficulty with complex auditory directives, appreciation and discrimination of music, and identification and discrimination of environmental sounds (Fausti et al., 2009; Musiek, Baran, & Shinn, 2004). Frequency and severity of central auditory deficits are variable and unpredictable in head injuries and often times can be confused with cognitive deficits and for combat veterans can also be confused with post-traumatic stress disorder (PTSD). This underlines the importance of an interdisciplinary evaluation to ensure accurate diagnosis. Variability in central auditory deficits can be seen across the age range as older adults are at an increased risk of subdural hematomas and increased intracranial pressure. Increase in these types of injuries can lead to an increase in central auditory deficits. In addition, the cognitive aging process affects neural plasticity within the central auditory nervous system which could affect the prognosis for older adults following a head injury. As individuals age there is a decline in neural plasticity within the brain. Therefore, an older individual with TBI and decreased neural plasticity will have a poorer prognosis compared to a younger individual with TBI and greater neural plasticity. Acquisition of a head injury in conjunction with the normal age related declines in both peripheral and central auditory processing can put older adults at a disadvantage and limit their success with auditory rehabilitation compared to younger adults. (Kinsella, 2011).

Tinnitus

Another consequence of TBI is the acquisition of tinnitus. Hearing loss and tinnitus are often associated with each other; therefore individuals with head injury who have decreased hearing acuity also often report tinnitus. Lew et al. (2007) reported that in a group of individuals who had non-blast related head injuries, 18% reported tinnitus.

In a group of individuals with blast-related head injuries, 38% reported tinnitus. Tinnitus can also be a symptom of a number of other health problems including: stress, metabolic factors, problems in the heart and blood vessels, and problems associated with the jaw or neck. These health problems can also be associated with head injury; therefore the origin of the tinnitus is difficult to predict in head injuries. In cases where the tinnitus is associated with acquired hearing loss after head injury, individuals report that the tinnitus is of greater disability compared to the accompanying hearing loss (Fausti et al., 2009). This is most likely due to the sudden onset of the tinnitus after head injury in comparison to most cases where tinnitus has a gradual onset with the progression of hearing loss not related to head injury. Bergemalm and Borg (2005) found that 56% of individuals with head injury had tinnitus and that there was no correlation between the times elapsed since the head injury, the audiometric results, age, and gender. Due to the lack of correlation between all of these factors, Bergemalm and Borg suggested that there was a central component to the tinnitus and that the brain injury affects central mechanisms that cause tinnitus or the ability to suppress or cope with the tinnitus. In the general population, 80% of individuals with tinnitus are not bothered by their tinnitus and do not require intervention; however tinnitus in the remaining 20% is deemed to be “clinically significant” and requires some form of intervention (Lew et al., 2007).

Vestibular System

The balance system within the inner ear can also be disrupted following a head injury. A head injury can affect both the semicircular canals and/or the otolith organs that make up the balance system. Basford et al. (2003) suggests that approximately 30%

of individuals with TBI complain of impaired balance and coordination. Impairment of the vestibular system can also lead to dizziness, vertigo, and blurred vision. Vestibular system impairment associated with head injury can be either of peripheral or central origin. Peripheral issues that may result due to head injury are: hypofunction or lack of function of the peripheral vestibular system due to damage of the vestibular nerve or benign paroxysmal positional vertigo (BPPV) (Peterson, 2010). Due to acceleration/deceleration of the brain in the skull that results in a head injury, the otoconial debris can be thrown into different semi-circular canals causing post-traumatic BPPV (Ottoviano et al., 2009). A patient that has BPPV will experience a sudden sensation of spinning especially during certain head movements. Often times getting out of bed can elicit this spinning sensation. The otolith organs, the utricle and saccule, are responsible for sensing gravity and linear acceleration. Damage to these organs following head injury can lead to impaired ability to sense motion as well as impaired orientation to gravity. These deficits can cause disequilibrium and dizziness. A perilymphatic fistula as a result of head injury can also cause dizziness and vertigo. In some cases of head injury, the stapedius can be forced into the oval window which can cause a rupture resulting in a perilympathic fistula (Ottoviano et al., 2009). The perilymph then leaks out into the middle ear and can cause in addition to hearing loss, vertigo, nausea, and vomiting. Central vestibular deficits may also be present following head injury. Damage to the central vestibular system involves the brainstem or cerebellum. Resulting deficits from this damage can be impaired gaze stability and postural response (Peterson, 2010). The entire balance system that the body relies on involves not only the vestibular system, but also the visual system and proprioception. These systems work together to provide sensory information to the brain to maintain balance equilibrium. TBI's can also cause deficits to both the visual and proprioception systems; therefore damage to multiple portions of the balance system can lead to greater balance deficits. Involvement of multiple portions of the balance system following brain injury will have an impact on the prognosis of recovery from the brain injury, with a poorer prognosis being associated with multiple balance system deficits.

CHAPTER 3

THE ROLE OF THE AUDIOLOGIST AS A MEMBER OF THE MULTIDISCIPLINARY TBI TEAM

In order to receive comprehensive care for a TBI some individuals and their family members may seek the help of a multidisciplinary TBI team. This team is comprised of various professionals who specialize in the treatment and rehabilitation of TBI. The team works together as a single unit to provide care to the TBI patient as well as help family members make decisions in regards to what is the best medical and rehabilitative treatment for the patient. The team also functions as a support system for the family while providing them with educational information related to the medical and rehabilitative treatment of TBI. The team first evaluates the TBI patient and then creates a medical and rehabilitative plan for the patient. Finally, the team carries the plan out until all specific goals have been met while providing continuous care for any other medical or rehabilitative challenges that may arise along the way.

There are many benefits for individuals and family members who choose to seek out the help of a multidisciplinary team. Semlyen et al. (1998) conducted a study which examined the efficacy of a multidisciplinary team in the treatment of TBI. A comparison was made between treatment by a coordinated multidisciplinary team and treatment by a single discipline. The results suggest that although both treatment groups showed functional gains over the first 12 weeks post-injury, the group receiving multidisciplinary care continued to show functional gain for up to 2 years after injury while the group receiving single disciplinary care did not continue to make functional gains. In addition to evaluating the functional gains of the patients with TBI, the researchers also included information regarding psychological distress experienced by caregivers. The study found that caregivers of those individuals with TBI who were being treated by the multidisciplinary team had less psychological distress over time compared to caregivers of those who were being treated by an individual discipline (Semylen et al., 1998).

The professionals who make the multidisciplinary team are experts in regards to the medical and rehabilitative consequences of TBI that are associated with their respective fields. Meetings are held on a regular basis to discuss patient needs and goals. At this time ideas and recommendations can be shared and the group can come to mutual decisions to lessen or eliminate any miscommunications in regards to patient care. In many cases of TBI there are also other confounding injuries that may occur. For example, an active duty service member who experienced a blast injury is most likely going to have other physical injuries in addition to TBI. Therefore it is important for the multidisciplinary team to prioritize medical needs before certain rehabilitative goals can be met. Family members should be included in the medical and rehabilitative decisions as this can make them feel included in the rehabilitative process and also relieve some of the distress that they might be experiencing.

The members of the multidisciplinary team can vary depending on the type of setting. In general, there will be a physician who supervises the medical needs of the individual with TBI and monitors progress over time. In addition, a neurosurgeon/neurologist is responsible for monitoring of the brain activity following the injury. A team of nurses who specialize in TBI will also be there to care for the patient and to provide information to the family members in regards to daily care for the patient. In regards to the rehabilitative process the leader of the team is typically a physiatrist who specializes in physical medicine and rehabilitative care. They will assess the patient and decide on appropriate rehabilitation. A neuropsychologist assesses the TBI patient's changes in behavior and thinking following the injury. They can also act as a resource to family members to help them cope with these changes. Physical therapist and occupational therapist also play important roles on the team. The physical therapist focuses on maximizing physical independence by focusing on strength, balance, and coordination while the occupational therapist focuses on gaining independence in everyday life. For example, this could involve creating a plan to teach the TBI patient how to cook and do laundry again.

In addition to these professions, speech-language pathologist and audiologist are also important components to the professional team. The speech-language pathologist is responsible for assessing all aspects of communication. This includes: spoken language, written language, and cognitive-communicative functioning among many other areas (Coelho & DeRuyter, 1996). Lastly, the role of the audiologist is to assess the function of the auditory system and provide aural rehabilitation if necessary. Evaluation of the auditory system is crucial as auditory deficits can lead to impaired participation in other rehabilitative therapies. In order to effectively participate in all facets of rehabilitation it is crucial that auditory deficits have been addressed to maximize communication with other healthcare professionals. In addition, if the auditory system is not evaluated, auditory deficits can be mistaken for cognitive issues in the areas of attention and memory or in some cases can be mistaken for post traumatic stress disorder leading to misdiagnosis (Lew et al., 2010). Therefore the participation of the audiologist in the multidisciplinary team is critical for successful management of TBI.

Diagnostic Evaluation

The first step the audiologist must take in addressing potential auditory deficits in those with TBI is to complete a comprehensive audiologic evaluation. Ideally, this would involve behavioral tests as well as objective tests to obtain an accurate picture of the integrity of the auditory system. In addition, information regarding subjective impressions of hearing should be obtained from the patient and/or family member as this may be important when assessing central auditory function. Subjective information may also give the audiologist information on what tests should be used when completing the auditory evaluation. The specific tests that can be completed for individuals with TBI will depend on the severity of the head injury in conjunction with other confounding injuries. For some patients a complete evaluation can be completed in one session while for others it may take several sessions to obtain accurate results to make appropriate aural rehabilitation decisions.

Obtaining behavioral information is critical to assessing the integrity of the auditory system. The audiologist should obtain responses to air and bone pure tone stimuli and speech stimuli. This information should be ear-specific and should include threshold testing as well as supra threshold speech recognition testing. The behavioral audiogram provides the audiologist with information regarding the type and degree of hearing loss. The type of transducer used to obtain these results will vary depending on confounding injuries. Some individuals may have damage to the outer ear and insert earphones may be more appropriate to use compared to headphones. Due to the extent of head injuries, some TBI patients have had operations on either the brain or the skull; these patients may be more sensitive to the pressure of the bone conductor and a forehead placement may be more effective. In some cases, bone conduction results may need to be obtained at a later session when the head injury has had more time to heal. Behavioral diagnostic testing acts as the foundation for determining function of the auditory system and can be used in conjunction with objective tests to obtain an accurate representation of auditory function.

There are several objective tests that can be used in addition to behavioral testing. The first test that can be used is tympanometry. Tympanometry provides information about the integrity of the middle ear. Due to the higher prevalence of tympanic membrane perforation in individuals with TBI, especially those who have experienced blast injuries, tympanometry is an important test to utilize. It can be used to confirm or rule out the presence of a perforation. The suspected presence of cholesteatomas and ossicular chain discontinuity can also be evaluated using tympanometry in conjunction with other testing. While differential diagnosis of middle ear pathology is not possible with tympanometry alone, abnormal tympanometric results warrant further evaluation by an otologist (Shanks, 1984). Acoustic reflex testing can also be used to evaluate both the ipsilateral and contralateral auditory pathways and gives information about the integrity of both the seventh and eighth cranial nerves. Otoacoustic Emissions (OAEs) can also be evaluated in individuals with TBI. OAEs assess the function of the outer hair cells within the cochlea. It should be noted that absence of OAEs is not always suggestive of cochlear dysfunction. In cases of middle ear pathology, OAEs will be absent due to the inability of the emission to pass through the damaged middle ear system. Additionally, present OAEs alone cannot confirm the presence of normal auditory function as they are only an evaluation of cochlear function and cannot give information regarding the auditory nerve and the brainstem (Cevette, 1995). Each of these measurements can be made without response from the individual being tested. This gives the audiologist the ability to gain some general information in regards to the function of the auditory system until accurate behavioral results can be obtained.

Some individuals with TBI are unable to respond behaviorally, or due to cognitive deficits are unable to provide accurate responses. In these cases, the audiologist can use electrophysiologic measures to assess the integrity of the auditory system. Use of these measures allows the audiologist to obtain ear-specific and frequency-specific auditory information without a response from the patient. Although behavioral results are the most accurate, electrophysiologic measurements can help estimate hearing thresholds. The diagnostic test that is used to obtain these thresholds is the auditory brainstem response (ABR). The ABR is an electrophysiologic response of the central nervous system to an auditory click stimulus and is characterized by five neurogenic waves (Lew et al., 2004). This test can be performed in a non-sedative state; however due to the severity of some head injuries cooperation still cannot be obtained from the patient for the procedure. Excessive movement and lack of relaxation can cause artifact in the response and comprise the accuracy of the results. If this occurs it may be more beneficial to obtain results during sedation especially if the patient has additional medical procedures that need to be completed under anesthesia. At this time, the audiologist should be able to complete the ABR measurement without incident and obtain accurate information about the auditory system. The results of the ABR give the audiologist information on the type and degree of hearing loss which can be used in the development of an aural rehabilitation plan.

In addition to the audiological evaluation, the audiologist is also responsible for conducting a vestibular evaluation on those with TBI who have specific complaints about dizziness and/or balance. There are a number of vestibular tests that can be completed to assess the integrity of the vestibular system. For TBI patients specific vestibular tests have been found to be sensitive to different mechanisms of injury. TBI patients who suffer from blunt head trauma are more likely to suffer damage to the horizontal semicircular canal and are more likely to develop BPPV compared to those who suffer blast related injuries (Franke et al., 2012). Videonystamography (VNG) and rotational chair testing evaluate the function of the horizontal semicircular canal and therefore can be used to evaluate TBI patients with blunt head trauma. Within the VNG test battery, bithermal calorics are most sensitive to deficits within the horizontal semicircular canal. Also within the VNG test battery, the Dix-Hallpike maneuver is used for diagnosis of BPPV.   Each of these tests has the ability to localize a lesion to a specific ear or determine that both vestibular systems are impaired due to head injury. For blast-related TBI patients damage to the vestibular system is more localized to the otolith organs; however, it is still possible to see both peripheral and central deficits in other areas of vestibular testing when examining these individuals. There are two diagnostic tests that evaluate the otolith organs. The subjective visual vertical (SVV) test evaluates utricular function while the vestibular-evoked myogenic potential (VEMP) is a measure of saccular function.

Each of these vestibular diagnostic can aid in determining the location of vestibular deficits. While it is not within the audiologist's scope of practice to treat vestibular deficits, the information gathered during diagnostic evaluation can assist in rehabilitation. Physical therapists that specialize in vestibular rehabilitation can use the information provided by the audiologist's diagnostic testing to create an appropriate rehabilitation plan based on the location of the vestibular lesion. Deficits in vision and proprioception, which also contribute to balance, can be mistaken as vestibular system dysfunction. If the vestibular evaluation is unremarkable, then it is the responsibility of the audiologist as part of the interdisciplinary team to make a referral to a neurologist, ophthalmologist, and/or physical therapy for rehabilitation focusing on proprioception.

As a member of the interdisciplinary team the audiologist should also be well versed in the diagnosis of auditory processing disorders. It is not surprising with the nature of head injuries that deficits in central processing abilities can be observed. There is currently no standard in regards to the diagnostic tests that should be used for evaluation but a variety of tests should be used to evaluate all aspects of auditory processing. This may include but are not limited to: the Staggered Spondaic Words (SSW) test, Gaps-in-Noise (GIN) test, masking level difference (MLD), and speech in noise testing. The SSW evaluates the dichotic listening abilities of an individual while the GIN evaluates temporal processing abilities. The MLD examines the binaural processing abilities and localization of the listener while speech in noise testing evaluates hearing abilities in adverse listening conditions. Each of these tests evaluates a different aspect of auditory processing and therefore allows the audiologist to obtain a complete picture of processing abilities beyond the peripheral auditory system. In addition to these behavioral tests it is also important to consider the patient's auditory complaints. For many TBI patients, peripheral hearing sensitivity remains intact but their subjective complaints of auditory deficits remain significant. Therefore, the audiologist should have detailed knowledge of the patient's complaints as well as the specificity, reliability, and validity of the variety of auditory processing tests that are available (Myers et al., 2009). While deficits on these tests can signal central auditory dysfunction, audiologist should use caution in diagnosing auditory processing disorders in individuals with TBI. In the case of this specific population, there are a number of confounding factors that can lead to misdiagnosis. Individuals with TBI often have co-morbid injuries that can affect their ability to perform adequately on central auditory testing. Many TBI patients are on medications to manage other injuries and these medications can affect their ability to attend to the task as well as cause them to have increased fatigue which could affect interpretation of diagnostic testing. More specific to head injury, there can also be deficits in cognitive abilities. Unique to almost all individuals with TBI is cognitive impairment that results in an alteration in arousal and slowed processing speed, difficulty multi-tasking, and reduced cognitive stamina (Myers et al., 2009). It is the job of the audiologist with the help of other members of the interdisciplinary team to determine if diagnostic findings reflect a true deficit in central auditory processing or if results are skewed by other confounding factors.

The cognitive deficits seen in individuals with TBI can not only be reflected in diagnostic results of auditory processing but also in other audiological behavioral testing. Due to confounding cognitive deficits, careful consideration should be taken in interpreting all behavioral test results in this patient population. In addition, it is important for the audiologist to know the limits of the TBI patient so adjustments can be made to testing procedures. For those who cannot verbally respond to a behavioral task this may mean raising a hand, raising a thumb, or even responding by headshake. Inability of the patient to effectively verbally communicate can also affect the validity of speech recognition testing. In some cases where TBI patients fatigue quickly, testing may need to be completed in more than one session with objective testing done first and behavioral testing completed when the patient is more stable and can consistently respond. Limits of the patient during testing can also aid the audiologist in making appropriate rehabilitation recommendations based on the patient's limitations. These special considerations elicit the need for an experienced audiologist who can modify test procedures and obtain the most useful and accurate diagnostic information from patient's with TBI.

Management of Auditory Deficits and Tinnitus

An audiologist working with patients with TBI should be experienced with traditional management strategies such as hearing aids for hearing loss, but it is also important that they have experience in management of tinnitus and auditory processing disorders. Early diagnosis and intervention for any audiological consequence associated with TBI is essential to minimize communication deficits. Unaddressed auditory dysfunction can affect the overall rehabilitation process for an individual with TBI (Lew et al., 2009). Auditory dysfunction that goes undiagnosed and untreated can lead to misdiagnosis which can further impede the rehabilitation process for these individuals. Therefore, the audiologist is a key member of the interdisciplinary team.

For some individuals with TBI, conventional amplification may be the most appropriate management strategy. The audiologist is responsible for the appropriate selection and fitting of the hearing aids based on the degree and type of hearing loss of the TBI patient. Depending on the severity of the hearing loss and self-perception of communication deficits it may be beneficial for the audiologist to select a hearing aid that is compatible with accessories such as FM or remote microphone technology that can assist in hearing in adverse listening situations. For patients impacted by hearing loss and tinnitus due to TBI-inducing trauma, selection of a hearing aid with a built-in tinnitus masker may be warranted to be used not only to address hearing loss but also to help manage tinnitus. Any hearing aid selected and fit to a patient should be verified to not only ensure appropriate amplification but also to serve as a benchmark for comparison of future hearing aid adjustments (AAA, 2006).

For individuals with head injuries associated with severe to profound bilateral hearing loss, a cochlear implant may be appropriate. An evaluation not only by the audiologist but also by a number of other professionals is warranted to determine appropriate candidacy for a cochlear implant. As a team, an examination of the patient's audiological, physical, and mental status is conducted and candidacy is determined. In addition to the candidacy evaluation the audiologist is also responsible for counseling the patient and their family about realistic expectations of a cochlear implant and informing the family of the importance of support during the aural rehabilitation process following implantation.

The audiologist is also responsible for management of tinnitus associated with TBI. While there is currently no cure for tinnitus, there are a number of treatment strategies that can be used to manage tinnitus. There is no definitive evidence supporting one particular tinnitus management intervention; therefore it is the audiologist's decision on what strategy to utilize based on the patient's needs. Most tinnitus management strategies involve counseling by the audiologist and sound management/therapy. Henry et al. (2005) described a clinical trial comparing the efficacy of the tinnitus retraining therapy (TRT) and tinnitus masking. TRT involves low-level sound therapy, not necessarily ear level devices, to habituate to the tinnitus. TRT also requires recognition of the limbic and autonomic nervous system contributory effects on an individual with tinnitus. Tinnitus masking involves wearing an ear-level device and "covering up" the tinnitus (Henry et al., 2005). The clinical trial found that in the short-term both interventions showed comparable improvements, but in the long-term TRT showed greater improvements. It should be noted that the individuals in the tinnitus masking group did not receive the same amount of counseling as the TRT group. Due to the success of TRT in the long-term it was suggested that individuals with more severe tinnitus utilize TRT while those with moderate tinnitus utilize tinnitus masking to provide a sense of immediate relief. Henry et al. (2008) proposed a sound-based tinnitus management program for clinical application by audiologists that can accommodate all individuals with varying severities of tinnitus. This program is called progressive tinnitus management and it is currently being utilized in the VA system; however clinical efficacy has not been reported at this time. The management program is divided into five levels and is designed so that intervention is provided only to the degree necessary to meet the variable needs of each patient. Patients proceed through each level until successful management of tinnitus is accomplished. For some patients this may be as simple as addressing tinnitus with the use of hearing aids. For many individuals, hearing loss and tinnitus are associated with one another and once the hearing loss has been addressed the tinnitus has also been better managed with the use of amplification. For others further management strategies are needed which may include attending a class to discuss the development of a sound management plan. A sound management plan is created by having the patient choose a number of sounds (soothing, interesting, or background) that are expected to be effective in managing a specified tinnitus problem situation (Henry et al., 2008). Providing acoustic stimulation can reduce the perception of tinnitus and in return make it less bothersome to an individual and minimizes the negative effects it may have on a person such as stress and irritability. There are few individuals who need tinnitus management beyond development of a sound management plan. These individuals require one-on-one intervention with an audiologist to address sound management and they may also require use of ear-level tinnitus maskers or sound generators. This would be considered the highest level of tinnitus management according to Henry et al. (2008). While the progressive tinnitus management program is not the only way that tinnitus can or should be addressed, it provides an individual with a number of resources to address the negative consequences of tinnitus. Due to issues regarding scope of practice and time constraints many audiologists do not offer tinnitus evaluation or intervention. However, it is imperative that the audiologist be able to refer patients to professionals who have interest and experience in tinnitus management. In some cases, tinnitus may be a symptom of a treatable disease and referrals to other health care professionals are commonly indicated (AAA, 2001). Some of the professionals who may be consulted for their services include: otolaryngology, psychiatry, psychology, and neurology.

As part of the interdisciplinary team, the audiologist is also responsible for the development of a rehabilitation plan to address auditory processing deficits in patients with TBI. Early intervention for auditory processing disorder (APD) is crucial to take advantage of the brain's plasticity. The longer the individual goes without intervention the more difficult it may be to re-train or re-wire the brain to accomplish different tasks. Similar to tinnitus management, there is no standard on addressing auditory processing disorders. ASHA (2005) recommends an interdisciplinary approach involving the collaboration of the audiologist, speech-language pathologist, and other professionals such as a physical therapist. The rehabilitation plan should include both bottom up and top down approaches. Bottom up approaches include signal enhancement and auditory training while top down approaches include cognitive, metacognitive, and language strategies. Acoustic signal enhancement can be accomplished with the use of an FM system. The FM system is designed to improve the signal-to-noise ratio in a particular listening situation which enhances the acoustic signal for the listener. More recently, hearing aid manufacturers have introduced remote microphone technology that works in a similar manner as an FM with the goal of signal enhancement. The listener's communication partner wears a microphone and the signal from the microphone is wirelessly streamed directly to the hearing aids. This reduces the effects of distance between the speaker and background noise and enhances the signal. For individuals with normal hearing sensitivity, use of the remote microphone is accomplished through use of low gain hearing aids that are coupled to the remote microphone. Remote microphone technology is a more cost-effective alternative to an FM system. Signal enhancement can also be accomplished through the use of clear speech. Clear speech focuses on a slower rate, enunciating, emphasizing key words, and pausing more often (Musiek & Chermak, 2008). Another intervention approach is auditory training which is designed to change auditory behavior (ASHA, 2005). Auditory training activities may include: phoneme discrimination, temporal discrimination, localization/lateralization, temporal sequencing, and recognition of auditory information in the presence of background noise. The speech-language pathologist works with the audiologist to develop compensatory strategies for an individual with APD. Compensatory strategies are a top down approach used to minimize the residual effects of APD that are not resolved with the use of auditory training and signal enhancement (ASHA, 2005). This is accomplished by strengthening other higher order functions (memory, attention, and language). By capitalizing on these functions, residual effects of APD can be minimized and enhancements in communication, social, and learning outcomes can be seen.

Musiek and Chermak (2008) recommend that the treatment approach be customized based on the circumstances faced by each individual TBI patient. For patients with severe TBI, rehabilitation exercise may need to be modified. For example, breaking down the exercises into smaller steps will make the task easier to accomplish. Patients with TBI also benefit from structured therapy sessions in a quiet setting with minimal distractions. It is important for the audiologist to consider all deficits associated with the head injury to design a rehabilitation plan that is most appropriate for each patient's varying needs.

As with any practicing audiologist, it is important for the audiologist working with TBI patients to monitor hearing and progression with rehabilitation plans. For TBI patients with confounding injuries, several follow-up evaluations may be needed due to the inability to obtain accurate and comprehensive results during one testing session. In addition, monitoring of hearing is especially important for those TBI patients who have suffered an eardrum perforation resulting in a conductive hearing loss or fracture of the skull. As already discussed, there as an increased prevalence of tympanic membrane perforation among those who have suffered a TBI. This is especially true for patients who have been exposed to a blast which resulted in TBI. While most perforations of the eardrum will heal on their own, it is important for the audiologist in conjunction with an otolaryngologist to monitor the patient during the healing process. If the perforation does not resolve on its own, the otolaryngologist may need to proceed with medical treatment to repair the perforation. For any patient who has had an eardrum perforation, there is an increase in the chance of developing a cholesteatoma (Fausti et al., 2009). Therefore, continued monitoring of hearing and middle ear status by an audiologist is important to ensure infection in the middle ear or erosion of the ossicles has not occurred and if it has medical treatment by the otolaryngologist can be initiated. Bergemalm (2003) reported a higher incidence of progressive hearing loss with head injuries related to skull fractures. Due to the increased incidence, the audiologist should evaluate the hearing of individuals with skull fracture on a routine basis to ensure hearing has not progressed or to recommend a treatment plan if the hearing loss has progressed beyond the normal range of hearing.

It is the responsibility of the audiologist to determine how often monitoring of hearing should occur and will vary depending on the individual patient. Changes in hearing should be documented and if the patient utilizes amplification, the audiologist should make adjustments to the hearing aids to provide appropriate gain based on changes in hearing. The audiologist should also monitor the progression of patients who are being seen for tinnitus management and APD. Tinnitus management can be monitored by comparing pre/post subjective perception of hearing loss using patient questionnaires such as the Tinnitus Handicap Inventory (THI). Monitoring of success of rehabilitation of APD should be coordinated between the audiologist and speech pathologist. TBI patients who are successful in rehabilitation should see benefit from the use of signal enhancement, mastery of auditory training exercises, and utilization of compensatory strategies to minimize the residual effects of APD.

CHAPTER 4

CONCLUSION

Traumatic brain injury is a complex injury that can affect many systems within the body. Due to the complexity and variability of deficits associated with TBI, many patients and their families benefit greatly from being evaluated and treated by an interdisciplinary team that includes a variety of medical and rehabilitative specialists. The goal of the interdisciplinary team is to collaborate as a group and make recommendations for appropriate medical treatment and rehabilitative needs.

In addition to cognitive and physical deficits, auditory dysfunction can also be associated with TBI. Dysfunction has been reported in both the peripheral and central auditory systems and may include hearing loss, tinnitus, and auditory processing deficits. In addition to auditory deficits, abnormalities of vestibular function have also been reported following TBI. Tinnitus is also a common consequence for the TBI population.

These audiological and vestibular abnormalities warrant the need for an audiologist to be included on the interdisciplinary team. The audiologist is responsible for performing diagnostic testing and working with the interdisciplinary team to determine the most appropriate treatment and rehabilitative plan for the TBI patient and their family. Monitoring of hearing acuity, especially for eardrum perforation and skull fractures, and evaluating the effectiveness of tinnitus and APD management are also the responsibility of the audiologist. The audiologist collaborates with the interdisciplinary team to ensure successful rehabilitation of the individual with traumatic brain injury.

REFERENCES

American Academy of Audiology (AAA). (2001). Audiologic guidelines for the diagnosis and management of tinnitus patients. Retrieved May 5th, 2012 from http://www.audiology.org/resources/documentlibrary/Pages/TinnitusGuidelines.aspx

American Academy of Audiology (AAA). (2006). Guidelines for the audiological management of adult hearing impairment. Retrieved May 5th, 2012 from http://www.audiology.org/resources/documentlibrary/Documents/haguidelines.pdf

American Speech Language Hearing Association (ASHA). (2005). (Central) auditory processing disorders- the role of the audiologist [Position Statement]. Available from www.asha.org/policy.

Basford, J., Chou, L., Kaufman, K., Brey, R., Walker, A., Malec, J., Moessner, A., & Brown, A. (2003). An assessment of gait and balance deficits after traumatic brain injury. *Archives of Physical Medicine Rehabilitation, 84*, 343-349.

Basson, O. & Van Lierop, A. (2009). Conductive hearing loss after head trauma: review of ossicular pathology, management and outcomes. *Journal of Laryngology & Otology, 123*, 177-181.

Bergemalm, P. (2003). Progressive hearing loss after closed head injury: a predictable outcome? *Acta Otolaryngology, 123*, 826-845.

Bergemalm, P. & Borg, E. (2005). Peripheral and central auditory sequelae of closed head injury: function, activity, participation and quality of life. *Audiological Medicine, 3*(3), 185-198.

Cannon, R. & Jahrsdoerfer, R. (1983). Temporal bone fractures: review of 90 cases. *Archives of Otolaryngology-Head and Neck Surgery, 109*, 285-288.

Center for Disease Control and Prevention (CDC). (2010). Traumatic brain injury in the United States: emergency department visits, hospitalizations and deaths 2002-2006.

Cevette, M. & Beliek, D. (1995). Transient evoked and distortion product otoacoustic emissions in traumatic brain injury. *Journal of the American Academy of Audiology, 6*, 225-229.

Coehlo, C. & DeRuyter, F. (1996). Cognitive-communicative disorders resulting from traumatic brain injury in adults. *Journal of Speech, Language, and Hearing Research, 39*, S5-S17.

Fausti, S., Wilmington, D., Helt, P., Helt, W., & Konrad-Martin, D. (2005). Hearing health and care: the need for improved hearing loss prevention and hearing conservation practices. *Journal and Rehabilitation Research and Development, 42*(4), 45-62.

Fausti, S., Wilmington, D., Gallun, F., Myers, P., & Henry, J. (2009). Auditory and vestibular dysfunction associated with blast-related traumatic brain injury. *Journal of Rehabilitation Research and Development, 46*(6), 797-810.

Franke, L., Walker, W., Cifu, D., Ochs, A., & Lew, H. (2012). Sensorintegrative dysfunction underlying vestibular disorders after traumatic brain injury: A review. *Journal of Rehabilitative Research and Development, 49*(7), 985-994.

Henry, J., Schechter, M., Loovis, C., Zaugg, T., Kaelin, C., & Montero, M. (2005). Clinical tinnitus management using a "progressive intervention" approach. *Journal of Rehabilitative Research and Development, 42*(4), 95-116.

Henry, J. A., Zaugg, T. L., Myers, P. J., & Schechter, M. A. (2008). Using therapeutic sound with progressive audiologic tinnitus management. *Trends in Amplification*, 12 (3), 188-209.

Kinsella, G. (2011). What are the characteristics of traumatic brain injury? *Brain Impairment, 12*(1), 71-75.

Lew, H., Jerger, J., Guillory, S., & Henry, J. (2007). Auditory dysfunction in traumatic brain injury. *Journal of Rehabilitation Research and Development, 44*(7), 921-928.

Lew, H., Garvert, D., Pogoda, T., Hsu, P., Devine, J., White, D., Myers, P., & Goodrich, G. (2009). Auditory and visual impairments in patients with blast-related traumatic brain injury: effect of dual sensory impairment on functional independence measure. *Journal of Rehabilitation Research and Development, 46*(6), 819-826.

Lew, H., Weihing, J., Myers, P., & Goodrich, G. (2010). Dual sensory impairment (DSI) in traumatic brain injury (TBI) - an emerging interdisciplinary challenge. *NeuroRehabilitation, 26*, 213-222.

Lyos, A., Marsh, M., Jenkins, H., & Coker, N. (1995). Progressive hearing loss after transverse temporal bone fracture. *Archives of Otolaryngology-Head and Neck Surgery, 121*(7), 795-799.

Munjal, S., Panda, N., & Pathak, A. (2010a). Audiological deficits after closed head injury. *Journal of Trauma: Injury, Infection, and Critical Care, 68*(1), 13-18.

Munjal, S., Panda, N., & Pathak, A. (2010b). Relationship between severity of traumatic brain injury (TBI) and extent of auditory dysfunction. *Brain Injury, 24*(3), 525-532.

Musiek, F., Baran, J., & Shinn, J. (2004). Assessment and remediation of an auditory processing disorder associated with head trauma. *Journal of the American Academy of Audiology*, *15*, 117-132.

Musiek, F., & Chermak, G. (2008). Testing and treating (C)APD in head injury patients. *The Hearing Journal, 61*(6), 36–38.

Myers, P. J., Wilmington, D. J., Gallun, F. J, Henry, J. A., & Fausti, S. A. (2009). Hearing impairment and traumatic brain injury among soldiers: Special considerations for the audiologist. *Seminars in Hearing*, *30* (1), 5-27.

National Institute of Neurological Disorders and Stroke (NINDS). (2002). Traumatic brain injury: hope through research. Retrieved January 8th, 2013 from http://www.ninds.nih.gov/disorders/tbi/tbi.htm

Ottoviano, G., Marioni, G., Marchese-Ragona, R., Trevisan, C., Filippis, C. & Staffieri, A. (2009). Anosmia associated with hearing loss and benign positional vertigo after head trauma. *Acta Otorhinolaryngologica Italica, 29*, 270-273.

Peterson, M. (2010). A case-oriented approach exploring the relationship between visual and vestibular disturbances and problems of higher-level mobility in persons with traumatic brain injury. *Journal of Head Trauma Rehabilitation*, *25*(3), 193-205.

Podoshin, L. & Fradis, M. (1975). Hearing loss after head injury. *Arch Otolaryngology, 101*(1), 15-18.

Semylen, J., Summers, S., & Barnes M. (1998). Traumatic brain injury: efficacy of multidisciplinary rehabilitation. *Archives of Physical Medicine Rehabilitation, 79*, 678-683.

Shanks, J.E. (1984). Tympanometry. *Ear and Hearing*, *5*, 268–280.